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BALLISTICALLY OPERATED WATER  
CANNON

AAI Corporation

Prepared for:

Army Land Warfare Laboratory

March 1974

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  <p>The primary purpose of this program was to develop, design and establish the feasibility of a cartridge actuated pumping system that will rapidly discharge discrete quantities of water at high pressure for crowd control purposes. Subsystem investigation was conducted to optimize cartridge performance with respect to desired pump output performance and establish the overall configuration of the system. Establishment of feasibility consisted of conducting a series of tests and demonstrations to determine the functional capability of the unit.</p>								

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## I. INTRODUCTION

The purpose of this program was to develop, test and determine the feasibility of a cartridge actuated water cannon for use in control of civil disorders.

In the area of civil disturbance and crowd control, new methods of crowd control are required. Fire hose type water streams are being used effectively but their chief problems are high water consumption and their requirement for installation of large and heavy engine and pumping equipment.

To alleviate these problems, an experimental single shot pulse jet water cannon was developed in an earlier experimental program in order to establish and define the size and characteristics of a single water pulse that could be utilized safely and effectively for crowd control. As a result of this effort, the single water pulse of 1.5 gallons projected through a 1.375-inch diameter nozzle at a pressure of approximately 175 psi was selected as the desired water pulse configuration for use in system development.

However, from an operational standpoint, the utilization of this pulse also requires its synthesization into a system containing elements which provide the necessary effective system operation. It was in this context that the basic requirements and objectives were formulated for the development of a system for rapidly projecting and controlling water pulses.

The approach to this problem was to provide a system concept that featured both the high potential energy inherent in a propellant for output performance and the use of a standard shotgun action for rapid and sustaining fire capability.

As a result of utilizing this approach in this program, a cartridge actuated water pump was developed that has demonstrable performance capabilities which basically match the stated flow rate requirements for a water pulse-type crowd control device. The basic advantage of the ballistic water pump is that it utilizes the high potential energy inherent in a small propellant cartridge to provide the necessary force for projecting the 1-1/2-gallon water pulse. Combining an automatic cartridge feed and ejection mechanism with the basic hydraulic projector provided a system which is capable of producing a completely controlled, yet high cyclic rate of fire.

The ballistic water cannon has seven primary advantages over a conventional pumping or compressed air system. First, the utilization of compact cartridges as an energy source negates the need for a motor or motor compressor installation. Second, the system is pressurized during actual firing of the pulse, hence the potential safety hazards have been greatly reduced. Third, the total amount and weight of hardware to store and project the payload is greatly reduced. Fourth, the projector can utilize non-pressure water tanks such as bladders which permit the optimization of tank configuration for a given vehicular installation. Fifth, the reduction in the number of pressurized pipe and hose connections and the elimination of

high pressure control devices, greatly reduce the probability of leaks and simplifies the preventative maintenance of the unit. Sixth, the system does not require prior pressurization or the running of pumps to be in the ready-to-fire condition. Seven, because of its compact size, it is adaptable to a dual projector configuration which would provide a wider area coverage.

## II. SUMMARY

The Cartridge Actuated Water Cannon whose design characteristics are shown below, was developed, designed, fabricated and tested for possible use in the control of civil disturbances. The use of the high potential energy inherent in a cartridge propellant coupled with the utilization of a standard 12-gauge shotgun action did achieve a fundamental improvement in a pumping system and met the output criteria with respect to the rapid discharge of discrete quantities of water at high pressure. The incorporation of the above two features into a model with system capabilities resulted in a unit that exhibited functional and operational capabilities to a degree necessary to demonstrate the feasibility of the concept. In this limited test program, problems with control-type mechanical mechanisms prevented further definitive conclusions.

### Design Characteristics of Cartridge-Actuated Water Cannon

#### Type of System

- o Cartridge-actuated double acting pump.

#### Modes of Operation

- o Single Shot
- o Semi-automatic Operation

#### Performance of System

- o Each shot projects 1.5 gallons of water through 1.35-in. dia. nozzle at a pressure of approximately 175 psi.
- o Rate of Fire - 1 shot per second.
- o Each cartridge magazine contains 20 rounds and has quick replacement capability.
- o Water Tank - non-pressurized type with the size limited by truck's weight capability.
- o Water Cannon Travel
  - Azimuth - 360° (continuous)
  - Elevation-Depression and Elevation

#### Safety Features

- o Trigger Safety
- o Burst disc on gas generator
- o Firing sequence initiated from open breech

### III. DESIGN APPROACH

#### A. General

The initial effort during this program was the acquisition, investigation and evaluation of engineering data and information which would have an influence on the design and performance of the cartridge-actuated ballistic water cannon. This effort, correlated with the objectives in Table I, resulted in the establishment of a design model which exhibited the operational and functional characteristics required for this type of weapon system. From a water expulsion standpoint, this model basically consisted of the following two interrelated major design areas or subsystems:

- o Differential Piston/Cylinder Assembly
  - o Water Expulsion Cylinder
  - o Hot Gas Generator
- o Cartridge Development

#### B. Differential Piston/Cylinder Assembly

The major emphasis was placed on the development of the differential piston/cylinder subsystem, which consists of the water expulsion cylinder and the hot gas generator, in order to quickly and accurately determine its water output capability with respect to the known performance of the earlier experimental unit (Exotech Unit).<sup>1</sup> The system output performance goal for the design model was to equal or exceed the following water output performance exhibited by the Exotech Unit:

- o 1-1/2 gallons per pulse
- o 175 psi (accumulator pressure)
- o 100 ft/sec (estimated muzzle velocity)
- o 1.38 in. nozzle diameter

However, this output data for the Exotech Unit was not completely defined in terms that could be directly applied to the design model (accumulator pressure was measured rather than hydrostatic pressure at the nozzle). Therefore, in order to insure that the design model's output performance would be equivalent to the Exotech Unit's muzzle and down-range output performance, a preliminary model (test fixture) shown in Figure 1 was designed and fabricated to experimentally determine the necessary expulsion design parameters.

##### 1. Preliminary Model

- o Design

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<sup>1</sup>The Exotech Unit is described in Technical Report No. LWL-CR-07M71, "Humane Crowd Dispersal: Pulsed Jet Water Cannon," Nov 71.

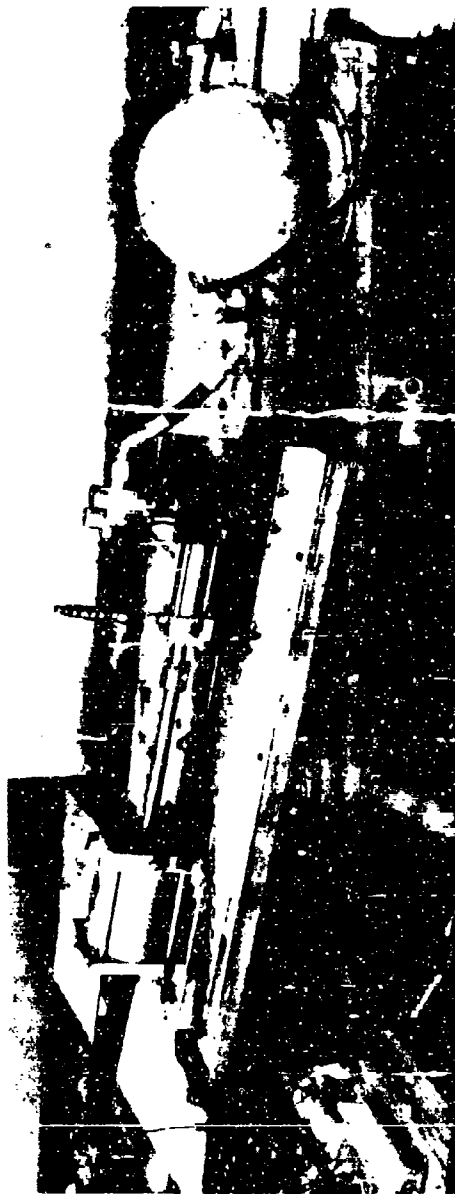


Figure 1. Preliminary Model, Water Cannon

TABLE I.

SUMMARY OF PROGRAM OBJECTIVES AND REQUIREMENTS

The system objectives are to achieve fundamental improvements in the rapid projection of discrete quantities of water at high pressure by utilizing the high potential energy inherent in a propellant and the design objectives which follow are representative of the design characteristics and features which should be incorporated into the proposed water cannon.

- a. Device should project 1.5 gallons of water through a 1.37 inch diameter nozzle at approximately a pressure of 175 psi.
- b. The device should have the capability of firing twenty shots without reload at a cyclic rate of .5 seconds per shot.
- c. A system which does not require permanent type mounting/stowage or precise alignments of components.
- d. Size of equipment in order to allow flexibility of vehicle's mission assignment
- e. Flexible system which can be easily mounted on various size vehicles.
- f. Eliminate use of auxiliary services (compressed air and electrical power) to support equipment.
- g. Greater operational reliability and minimum preventative maintenance due to elimination of auxiliary services and large number of high pressure fuel and air connections.

With regard to the above objectives, the establishment of design parameters and characteristics will be the basis for sub-system design and development. Sub-system test models of a single projector and gas generator will be designed, tested, and evaluated with the results being incorporated into a design of a feasibility model. The model will then be fabricated and tested for function and performance in order to determine the feasibility of the concept.

The model was designed to functionally simulate as closely as possible the proposed prototype unit and to meet the design objectives incorporated into the design model. The desired configuration assumed a water expulsion pressure of 175 psi and the piston ratio was selected to accommodate the optimum gas pressure recommended by the Olin Corporation for efficient cartridge burning.

The preliminary model consisted of an accumulator, a solenoid operated valve (with a large orifice), a high pressure gas cylinder (2.5 in. diameter with hydraulic buffer), coupled in series with a low pressure water piston (8 in. dia.) fitted with a 1.38 in. I.D. nozzle. The piston stroke was 8 inches, which provided a power stroke of at least 7 inches, (1-1/2 gal. of water from the 8-inch piston) before deceleration by the hydraulic buffer. This buffer was necessary to provide deceleration because there was no provision for automatic gas porting in the prototype.

The system operation was as follows:

- o With pistons in the most rear-ward position and a plug in the nozzle end, the 8-in. cylinder was filled with water.
- o The accumulator was pressurized with nitrogen or air to the desired test pressure.
- o On command, the solenoid valve was initiated with a switch which allowed the high pressure gas to drive the 2.5"-dia. piston and therefore the 8-in. piston forward, expelling the 1-1/2 gallons of water out through the nozzle.

#### o Test Data

Initial testing was performed to check out system functioning, water output pressure as a function of range, pulse coherency and to assess the terminal effectiveness of the water pulse at maximum range (90 feet). The assessment of the terminal effectiveness was performed by visual observation (pulse coherency on break-up) and an estimate of the impact energy transferred to a man target at a 90-foot range. (Shown in Table II.)

TABLE 11  
TEST RESULTS PRELIMINARY MODEL

Shot No.	Pressure PSI	Range Ft.	Target	Results Visual Observations
1	1100	100	Silhouette	REF SHOTS to provide testing point for demonstration.
2	1100	100	Silhouette	Ref target shot.
3	1100	100	Silhouette	Slightly wet slug, no water, good pattern.
4	1300	100	Silhouette	Improved slug, solid impact.
5	1300	100	Silhouette	Good slug, solid impact.
6	1300	100	4 x 4 PW	Excellent, best shot, knocked panel over.
7	1300	100	4 x 4	" , good shot, knocked panel.
8	1500	100	4 x 4	Good shot, decreased impact.
9	1800	100	4 x 4	Good shot, more spray, further decrease in impact.
10	1300		4 x 4	
11	1300	100	McGowan	Partial Hit
12	1300	100	4 x 4	
13	1300	100	McGowan	Subject expressed opinion that target compared favorably with Ex tech tests.
14	1500	100	McGowan	
15	1300	100	Monson	Missed.
16	1300	100	Monson	Stinging sensation which lasted for approximately 15 minutes.
17	1300	100	Monson	
18	180	100	4 x 4	Spray
19	1300	100	Hancock	Good hit, stinging sensation in mid.
20	1300	95	"	Hit helmet only.
21	1300	95	"	Good hit, stinging sensation.
22	1300	90	"	Missed
23	1300	90	"	"
24	1300	90	"	Good hit, 2-3 steps to recover, impact center of back.
25	1200	90	"	Good hit, impact from belt to back, buckled knees.
26	1400	100	4 x 4	1250 psi gave better results;
27	1250	100	4 x 4	both were good shots.
28	1800	142		1600 psi had the best range.
30	1400	149		The one shot at 175 ft. had good shot.
31	1600	145		were testing should be done to pl range vs. pressure curve.
32	1300	140		
33	1200	142		
34	1600	157		All tests appeared lower in range than previous data tests.

The test data shown in Table II provided insufficient information for definite conclusions and basically pointed out the need for some better means to evaluate output performance. The visual observation of water pulse coherency as a function of range was a poor measure of output performance due to the lack of specific terminal impact data. The impact test on individuals while providing a better measure of impact capability was difficult to describe accurately and analytically. In order to provide a better means for evaluating the unit's output water pressure with respect to the water pulse's terminal effectiveness at the target, a pendulum shown in Figure 2 was constructed. Basically this pendulum would measure the kinetic energy imparted to the pendulum by the impacting of the water pulse and thus provide a means of comparing the impact effectiveness of the various water pulses. The pendulum tests were conducted at 90 feet range as shown in Figure 3, for gas pressures of 1200, 1300, 1400, 1600 and 1800 psi and the resultant pendulum displacement data is shown in Table III.

One very important observation during the test and during later evaluation was that at the lower pressures less spray was produced and therefore appeared to give a better slug. At the higher pressures the spray prevented a good evaluation of the slug. The pendulum tests in Table III, however, indicated that the slug of water produced by the 1800 psi gas (176 psi water) produced the best impact even though a large spray was observed. Tests were performed with heavy brown paper on the pendulum target. Visual observation indicated that a spray approximately 4 to 6 feet in diameter hit the target but the brown paper, slightly wetted all over, had a 1-ft. to 1-1/2-ft. diameter mark which was super wetted. This agreed favorably with the area which was stinging during the subjective impact tests.

#### c Conclusions

After a thorough review of all the data and calculations of systems' performance it was decided to proceed with the following performance as the goal to be achieved -

- o Water pressure -- 175 psi average
- o Water volume -- 1.5 gal. projected before gas exhaust
- o Nozzle dia. -- 1.375 in.

The pendulum data was the major factor in this conclusion. It was also supported somewhat by the visual observation.

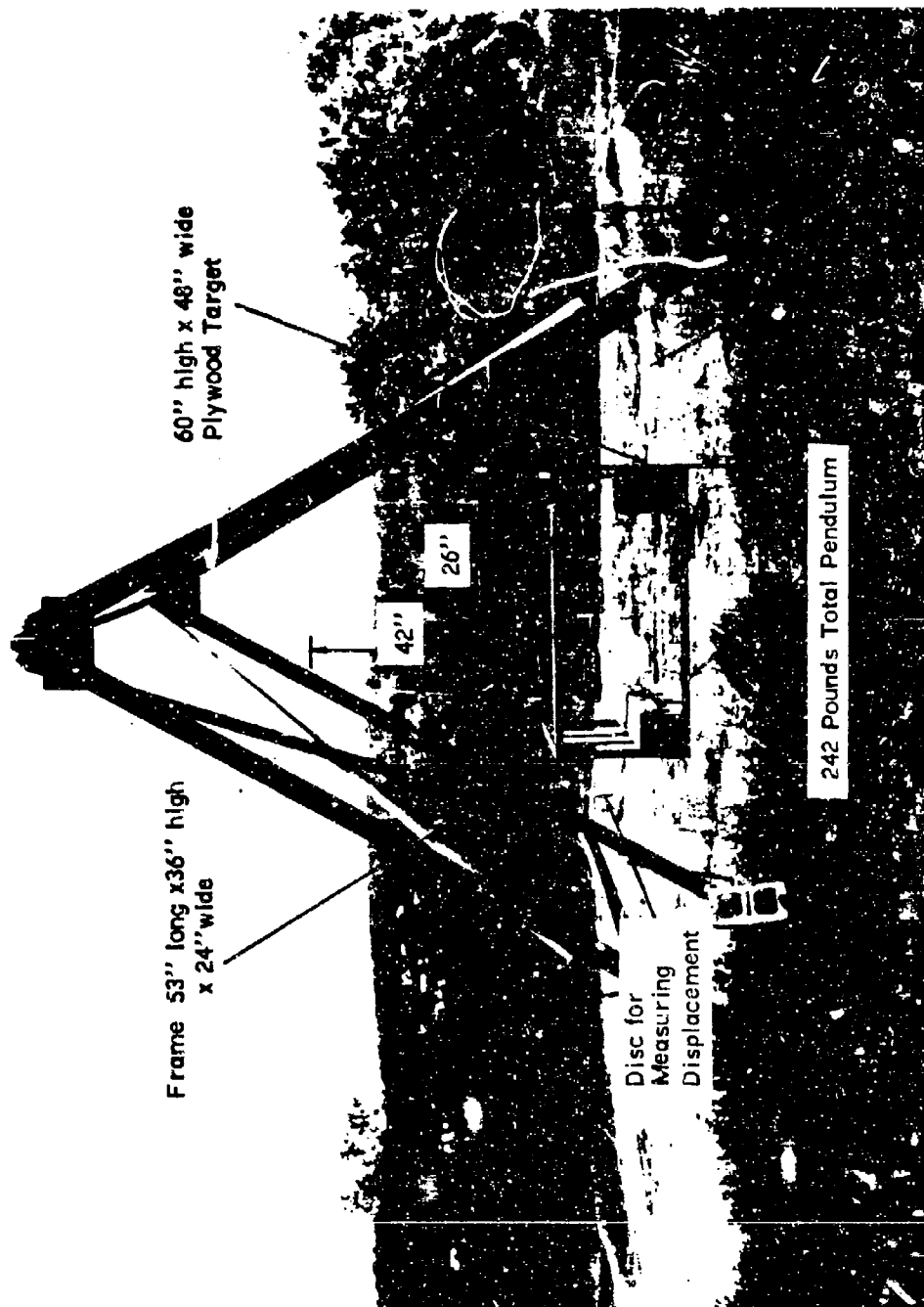


Figure 2. Test for Measuring Impact Energy

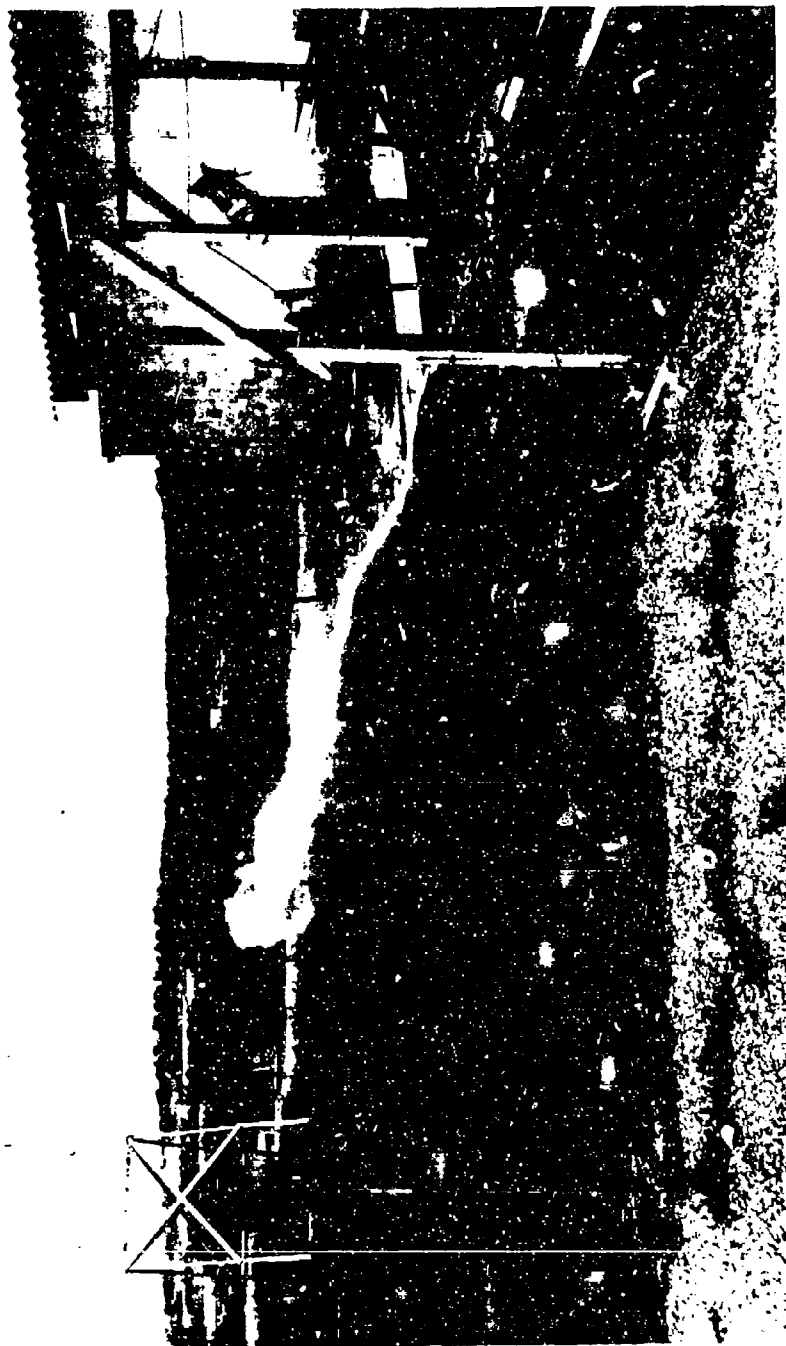


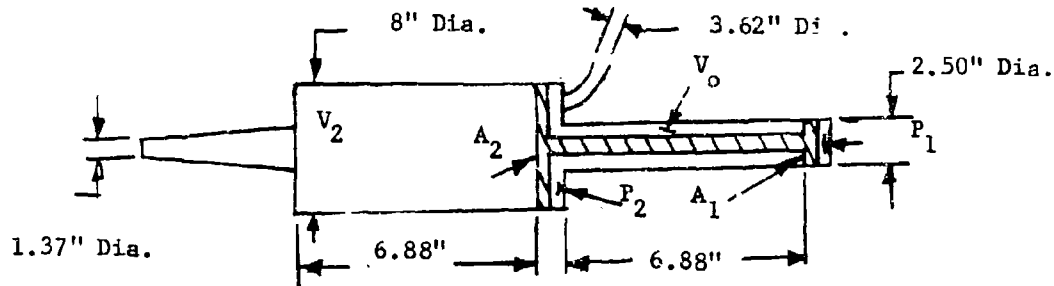
Figure 3. Water Slug Preliminary Model

TABLE III  
WATER CANNON TEST FIXTURE  
RESULTS OF TEST OF WATER SLUG  
ON BALLISTIC PENDULUM  
AT 90-FOOT RANGE

<u>Pressure</u>	<u>Pendulum Displacement</u>	<u>Average Distance</u>
1800 psi	11-3/8 inches	
1800	13-1/8 "	12.78
1800	14-1/8 "	
1600	10-1/2 "	
1600	11 "	(10.95)
1400	10-3/4 "	
1400	9-7/8 "	10.53
1400	11 "	
1400	10-1/2 "	
1300	10-3/4 "	
1300	8-7/8 "	
1300	9 "	10.39
1300	11-3/4 "	
1300	11-3/4 "	
1300	10-1/4 "	
1250	10-1/4 "	
1200	9 "	
1200	9-3/4 "	10.38
1200	12-3/8 "	10.38

## 2. Final Configuration

The above output performance data correlated with considerations of overall system size and the utilization of the Olin cartridge whose gaseous output is 35.7 in<sup>3</sup> of gas at 1800 psi in .140 seconds led to the following configuration.



$$\begin{aligned} V_2 &= 346 \text{ in}^3 & V_1 &= 35.7 \text{ in}^3 \\ P_2 &= 175 \text{ psi} & P_1 &= 1800 \text{ psi} \\ A_2 &= 50.265 \text{ in}^2 & A_1 &= 4.91 \text{ in}^2 \end{aligned}$$

The propellant cartridge selected for this configuration will expel the 1.5 gallons of water at a pressure of approximately 175 psi and supply the needed energy for the accomplishment of the fill and exhaust cycles. In the configuration selected the expulsion and fill cycles are interdependent and are accomplished concurrently. Based on a water expulsion velocity of approximately 161 fps, the time for water expulsion is .140 seconds. During this same cycle (.140 seconds) plus the anticipated delay in the return stroke due to exhaust time of approximately .2 seconds, water fill can be accomplished by the utilization of two 2.5 inch diameter fill lines.

Therefore the total time to expel water, exhaust hot gases through the port and water fill, which is basically the forward stroke, is .34 seconds. The next consideration is then to determine the spring force and time required to perform the return stroke which consists of the following four functions.

- a. Exhaust propellant gases through relief valve.
- b. Transfer the water from the rear to the front of the piston
- c. Drive the differential piston assembly to the rearward or firing position (including seal friction).
- d. Actuate the cartridge feed and ejection mechanism and final exhaust through breech.

Essentially, the force required to perform the above four functions (return stroke) is dependent on the desired time for the completion of this stroke. Since the desired total cyclic rate for this device is in the order of .5 seconds per cycle and the forward stroke requires .34 seconds, then the total time for the return stroke is .2 seconds. Therefore, the required spring force to return the piston in .2 seconds is the sum of the four forces and is calculated to be approximately 123 lbs. However, this was only an estimate to establish the general force level. The final spring that was developed empirically during test provided a range of force from 120 pounds preload to 250 pounds at compressed height.

#### C. Cartridge Development

##### o Design

The Gas Cartridge was designed and manufactured by Olin Corporation, Energy Systems Division, with AAI providing the Systems Design data. The standard 12-gauge shot gun cartridge was selected to house the propellant grain because it permitted the use of a standard shot gun pump action for cartridge feed and ejection in the final design.

The design parameters established for the cartridge and gas generator from the testing of the preliminary model at AAI are shown in Table IV.

The design program was conducted as follows:

- o Olin designed, constructed and tested a gas cartridge which would satisfy the requirements, when tested in a closed chamber of 2 in.<sup>3</sup> and a sized orifice, to simulate gas expansion in the gas generator of the preliminary design model.
- o AAI tested a sample of this design and forwarded the test data, conclusions and recommendations to Olin.

This process was repeated three times to assure the best cartridge design for the system within the available time. Further repeats of the process may evolve an even better cartridge for the system as performance

TABLE IV  
SPECIFICATIONS FOR GAS GENERATOR AND CARTRIDGE

I. Cartridge

- A. Consists of an Olin solid propellant grain, an igniter, and a percussion primer mounted in a standard 12 gage shotgun case.

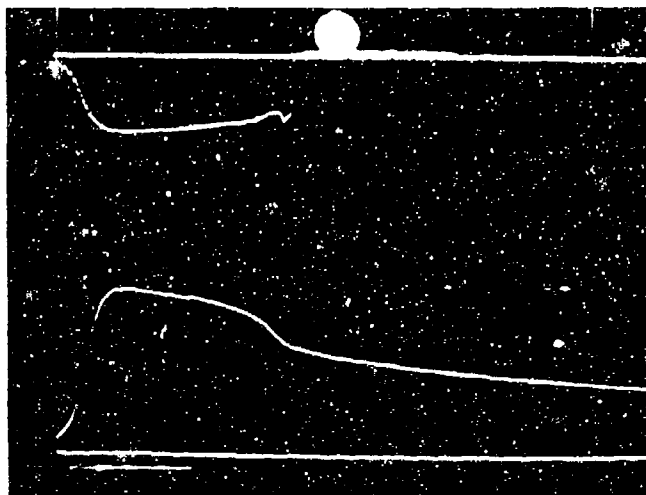
II. Performance Requirements of Gas Generator and Cartridge

- A. Ignition - To be fired by standard commercial shotgun action.
- B. Output - Constant pressure  $1800 \pm 100$  psi over full stroke and time.
- C. Time - .140 sec. duration.
- D. Stroke - 6.88 in.
- E. Bore - 2.5 in. dia.
- F. Volume - Initial volume  $2.0 \text{ in.}^3$   
Final volume  $35.7 \text{ in.}^3$
- G. Residue from cartridge - (preferably zero) non-corrosive and non hazardous to humans.
- H. Environmental goals - Operation conditions  $-25^{\circ}\text{F}$  to  $+125^{\circ}\text{F}$   
Storage conditions  $-65^{\circ}\text{F}$  to  $+140^{\circ}\text{F}$

data becomes available.

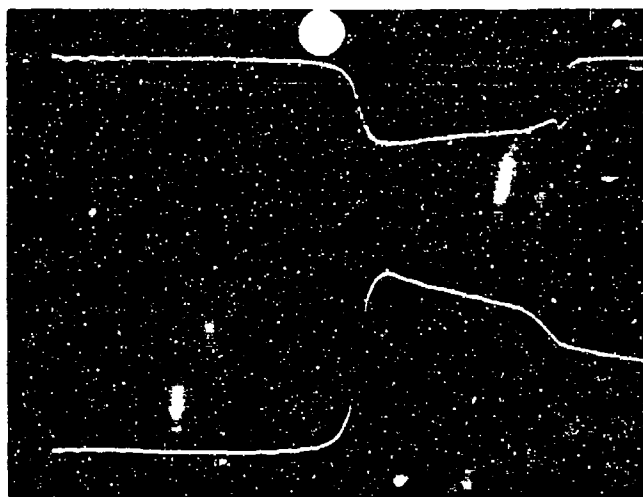
o Test Data and Conclusions

The cartridge specification called for 1800 psi  $\pm$  100 psi constant pressure over the full stroke. Olin did not produce a cartridge which would provide constant pressure over the full stroke, but the average pressure was approximately 1800 and the peak pressure did not exceed the 1900 by very much. After the third try at producing the constant pressure it was necessary to decide which cartridge, if any, would satisfy the needs of the program. It was concluded that the cartridge which produced the flattest curve, although not optimum, would provide a satisfactory device for feasibility study of the system and that further refinement could be accomplished at a later date. Olin later achieved an even flatter curve as shown in Figure 4, which provided a very satisfactory cartridge for system evaluation.



Water Pressure

Gas Pressure  
724 Psi/CM  
50 Mil Sec/CM



Water Pressure

Gas Pressure  
724 Psi/CM  
50 Mil Sec/CM

Figure 4. Cartridge Performance in Water Cannon Preliminary Model

#### IV. FEASIBILITY MODEL

##### A. Description and Discussion

###### 1. General

As a result of the design investigation and the testing of the preliminary test model, the feasibility model shown in Figure 5 was designed and fabricated. This cartridge actuated pumping device which can be operated and fired by a single operator was designed compactly for a truck installation and has the capability of projecting (pumping) 1.5 gallons of water per shot out through a 1.375 inch diameter nozzle at a pressure of 175 psi.

The unit is semi-automatic in operation, has a cyclic rate of approximately 1 shot per second and is magazine (20 cartridges) fed which provides the device with a rapid and sustaining firing capability. A universal type hydraulic trunnion is utilized for mounting the cannon to its support structure which readily enables the cannon to be manually aimed and controlled in azimuth and elevation.

The unit is self-contained in that it requires no auxiliary power services for operation and all firing and operating controls are located conveniently to the operator. A priming pump is provided on the tank to initially prime the cannon which will then retain its prime indefinitely. Once the unit is primed it requires only the insertion of the cartridge magazine to be in the ready condition to fire.

The major design elements of the devices are shown in Figures 6, 7 and 8 and the unit essentially consists of the following three subassemblies.

- o Water cannon and firing controls
- o Water cannon mount
- o Water tank

###### 2. Water Cannon and Firing Controls

The water gun and firing console is the primary unit of the system and is utilized for aiming, controlling and projecting the water pulse from the system to the target. It consists of the differential cylinder assembly, receiver assembly, receiver actuating mechanism, nozzle assembly, tip valve assembly and firing controls.

###### a. Differential Cylinder Assembly

The differential cylinder assembly is essentially a pneumatic/hydraulic linear actuator consisting of two different size cylinders integrally mounted in series with the pistons of both cylinders mounted to a common shaft. The configuration of the cylinders provide this device

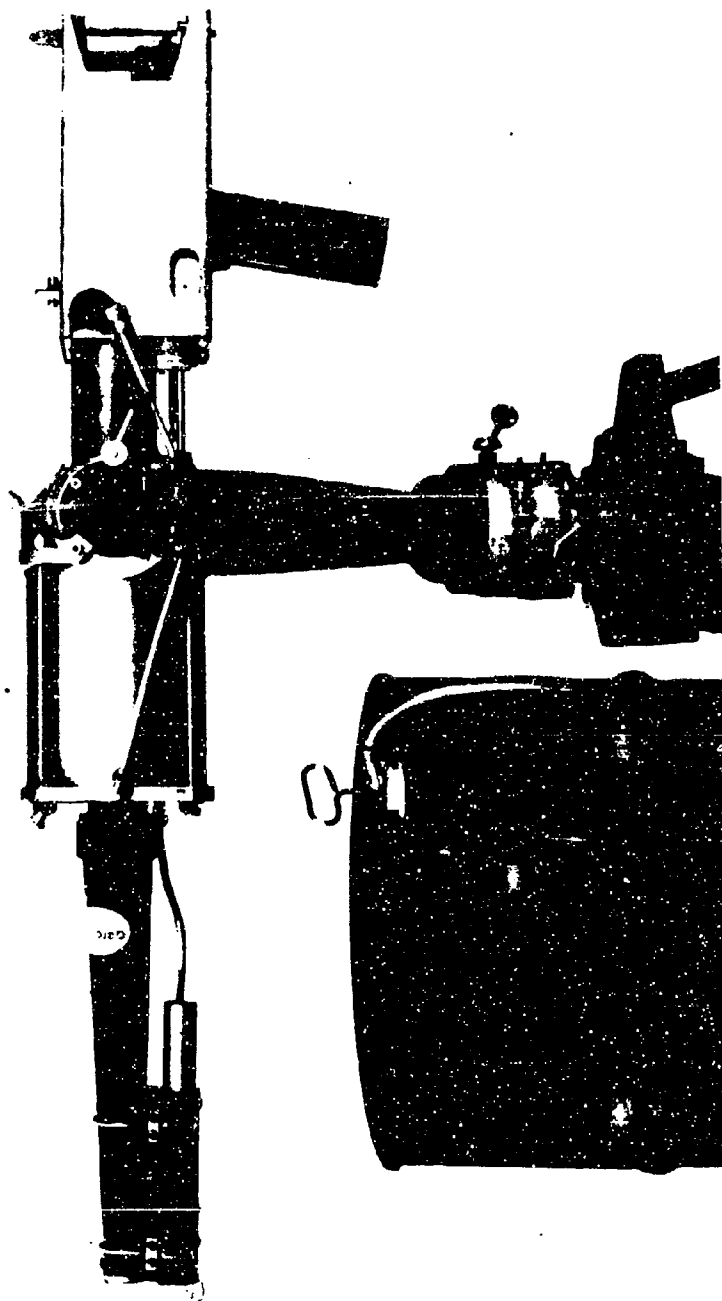


Figure 5. Cartridge Actuated Water Cannon

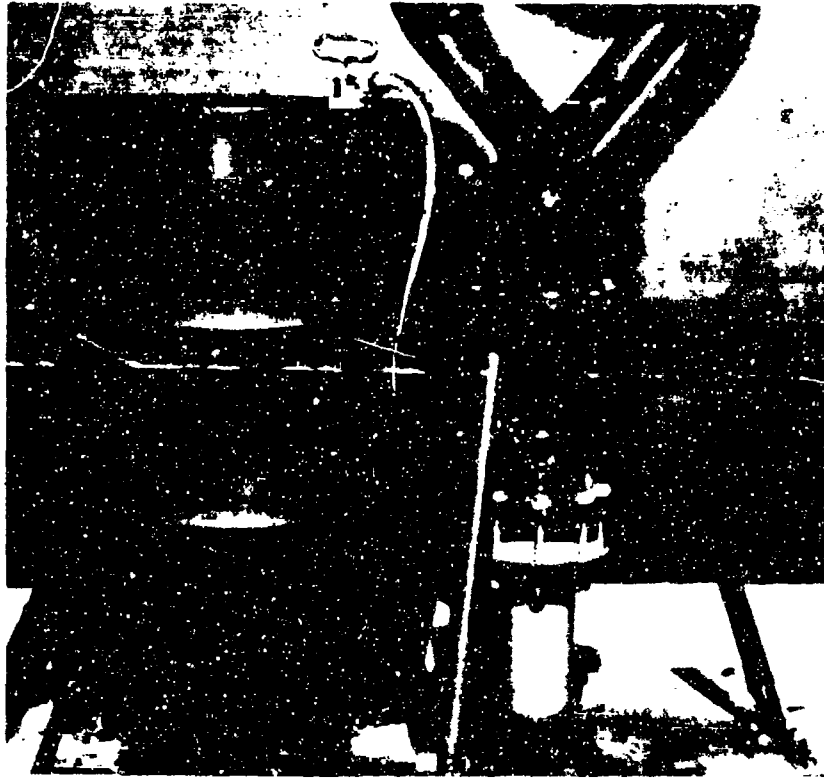


Figure 6. Water Cannon Reservoir and Mount

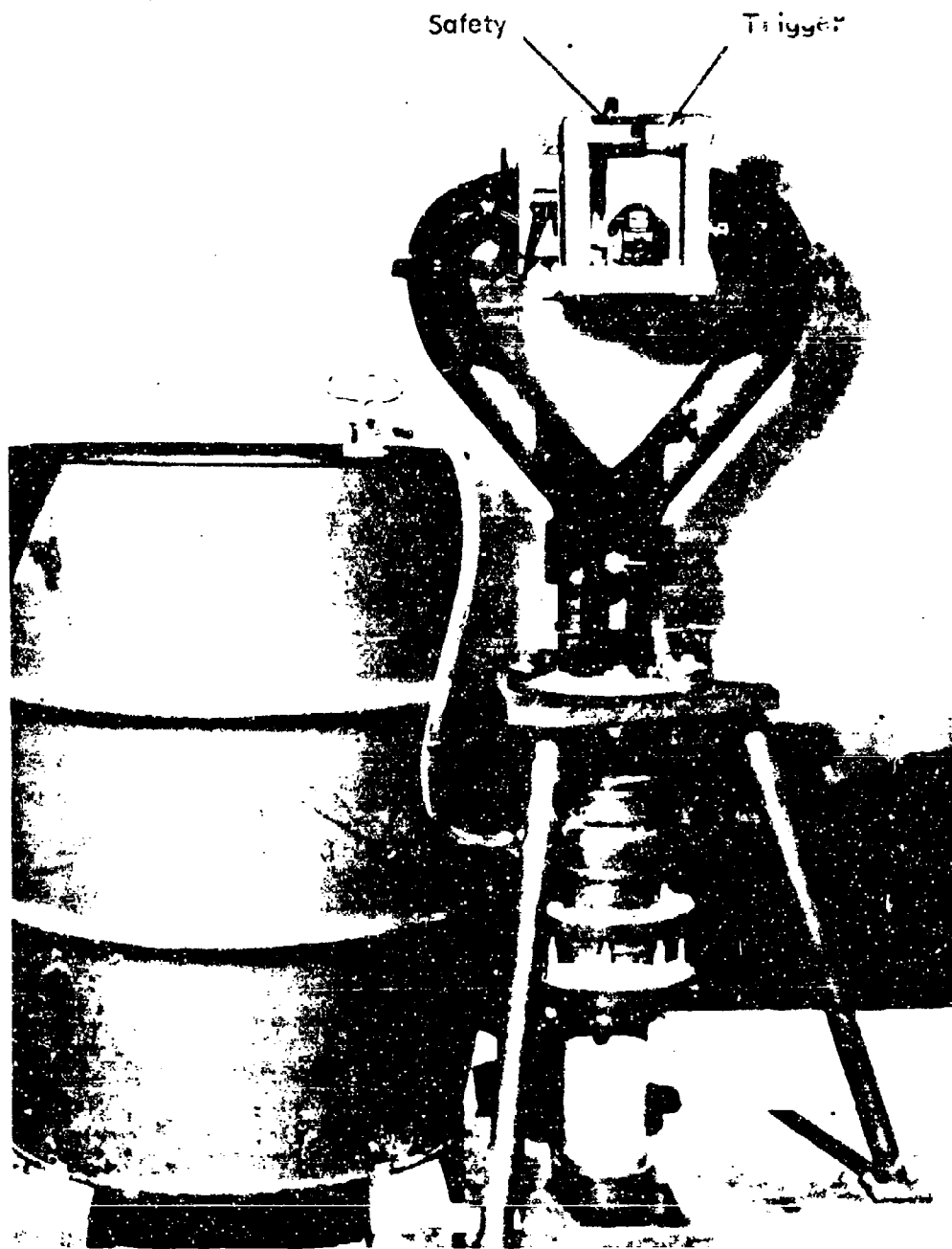


Figure 7. Water Cannon Rear View

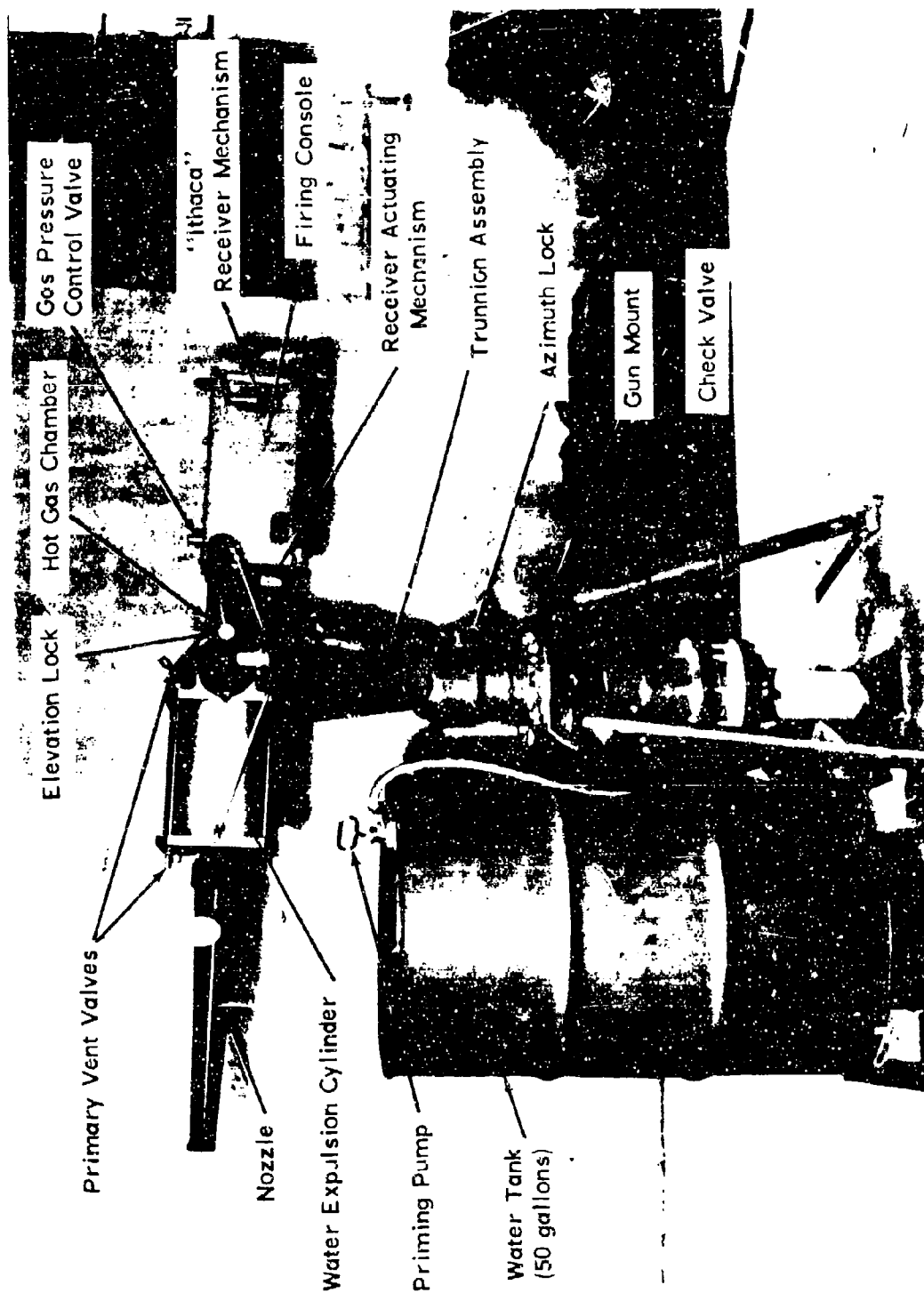


Figure 8. Water Cannon Side View

with the capability of reducing a given input pressure (1800 psi - hot gas) in the 2.5 inch diameter gas generator cylinder to the desired output pressure (175 psi - water) in the 8 inch diameter water expulsion cylinder. In this system, the small cylinder of the differential cylinder assembly is rigidly mounted and ported to the cartridge receiver to form the gas generator. This unit provides the motive force to actuate the large cylinder which from a system standpoint functions as a double acting water pump. The initiation of the cartridge in the gas generator provides the impetus for the power stroke which actuates the large cylinder expelling water from the cylinder through the nozzle, sucking water from the reservoir to the rear of the large piston and compressing the piston return spring. During the power stroke, the piston assembly travels forward a distance of 6.89 inches at which point the small piston of the gas generator passes over a .375 exhaust port in the cylinder which permits the hot gases driving the piston to exhaust to the atmosphere. At the completion of the exhaust cycle, the compressed spring then provides the force to return the piston assembly to its original position. During this return stroke six large check valves in the face of the large piston open, which permits the water in the rear of the cylinder to flow through the piston to the front of the large cylinder where it is then again ready for expulsion. In the design and development of the differential cylinder assembly, the use of hot high pressure gas for the actuation of the small cylinder side (gas generator) of the differential cylinder assembly presented difficulties in the following two inter-related areas.

- o Seal function and life
- o Excessive heat in gas generator and receiver

#### Seal Function and Life

In the design of the gas generator piston seals, the use of hot gas and the method utilized for exhausting the hot gases from the cylinder presented problems in the area of heat, dirt and the cutting action resulting from the seal sliding across the open exhaust port. This cutting action on the seal precluded the use of standard high temperature piston seals and required the use of hardened steel piston rings. This type of ring (internal combustion engine piston rings) provides an effective seal of the hot gases, is tolerant of operating in dirt environment and its basic rigid configuration permits it to slide across an opening in a cylinder wall without being deformed or nicked.

#### Excessive Heat in Gas Generator and Receiver

The heat problem in this area basically concerns the cartridge in the areas of safety and cartridge function. From a safety standpoint the problem was resolved by modifying the receiver (pump shotgun action) to fire from an open breech position. This method precluded the cartridge from being in contact with the hot firing chamber except during the actual chambering and firing sequence.

The problem of cartridge function in an excessively hot gas generator is basically one of the cartridge output consistency. However, to determine the effect of excessive generator temperature on cartridge output

by analytical or empirical methods is difficult to perform and to resolve. Consequently, for this program, it appeared that the controlling of generator temperature through the use of a simple heat exchanger offered a workable solution to this possible problem area. To achieve this solution required only the addition of thin wall diameter tube which would fit concentrically as a sleeve over the gas generator and permits water as a coolant to flow around the outer surface of the generator cylinder. The water is constantly circulated through this area by the pumping action of the expulsion piston which flows through two external lines to the sleeve.

#### b. Receiver Assembly

The receiver assembly of the water cannon utilizes the housing and the action from a 12 gauge Ithaca pump shotgun action for the firing chamber and the cartridge feed and ejection mechanism. The shotgun action was utilized because it provided a cartridge chamber and feed and ejection mechanism that was already developed and met all the structural and functional requirements for the water cannon.

The Ithaca Model-37 in particular was chosen because the strokes of its actuation most nearly met the required strokes of the differential cylinder assembly, and the safety and trigger were readily adaptable to the desired water cannon firing controls. The only major modification required to the Ithaca action was in the area of cartridge feed and the addition of a pressure burst disc. The cartridge feed portion of this action had to be redesigned to accommodate quick change compact 20 round magazine rather than the existing tubular magazine which contained the cartridges in tandem. The incorporation of a pressure burst disc assembly adjacent to the firing chamber of the receiver was for purposes of safety. This burst disc would rupture (2,500 psi) if excessive gas pressure is inadvertently produced in the generator.

#### c. Receiver Actuating Mechanism

The receiver actuating mechanism is utilized as a linkage assembly between the receiver and differential cylinder assembly for coordinating their functional activity, transmitting the forces and providing the necessary control to permit the overall assembly to function as a gun system. The forward stroke (firing) of the mechanism is controlled through a latch arrangement by the trigger and the rearward stroke is automatically performed by the return stroke of the differential piston assembly.

The basic forces utilized for actuating this mechanism and in turn the receiver action are derived from both the power and return stroke of the piston assembly (differential cylinder assembly). By utilizing the strokes of the piston assembly to actuate a control rod, the necessary timing for performing the following receiver functions in their proper sequence with respect to the piston assembly is achieved.

##### Return Stroke

o Return the receiver firing mechanism to an open bolt position which cocks the mechanism and trigger in preparation for the firing cycle.

o Extract the fired cartridge from the firing chamber which exhausts the residual gas and ejects cartridge from receiver.

o Feed the cartridge from the magazine to the cartridge feed tray in the receiver.

Forward Stroke (Activated by tripper)

- o Cartridge is aligned with firing chamber by feed tray.
- o Forward stroke of bolt inserts cartridge into firing chamber.
- o At completion of stroke, bolt is locked and firing pin is released for firing cartridge.

The control of this mechanism is performed by the trigger which consists of a set of linkages that provide the necessary cam force required to unlatch the cocked mechanism and permit it to go forward for the firing stroke. In order to provide the proper sequencing for the various receiver functions, a locking plate assembly and a series of interlocks are utilized which sequentially control the movement of the various push-pull type rods and linkage, each of which controls a specific receiver function.

In the modification of the standard shotgun receiver to provide a cartridge magazine feed capability, it was necessary to discard the magazine feed of the standard action and replace it with a new feed system that was compatible with the overall functioning of the new device. In order to achieve the proper sequencing and control in the movement of the cartridge from the magazine to the tray of the receiver, it was necessary to include this new feed system as an integral part of the receiver actuating mechanism.

Basically, this new feed system is utilized in conjunction with a twenty-round magazine in which the cartridges are spring loaded against a stop located at the top of the magazine. This feed system consists of a push-pull rod, the stroke of which pushes a single cartridge from the magazine to the receiver tray. The movement of this rod is caused and controlled by the reciprocating motion of the receiver actuating mechanism.

d. Nozzle Assembly

The "stang" nozzle assembly and flow straightener was selected for the cannon because it is a high performance nozzle; it met the configuration requirements for installation purposes and this particular nozzle was used in acquiring the background effectiveness data needed for determining the water cannon output characteristics.

e. Tip Valve Assembly

The tip valve is a pivot type valve that is pressure actuated and whose function with regard to overall system operation is as follows. Firstly, it prevents water draining from the nozzle and from the cylinder when the water cannon is in a level or depressed position. Secondly, it offers restraint to the flow of water from the device during the initial

firing cycle which restrains the piston assembly in the gas generator to the degree required for effective burning of the propellant. Thirdly, at the end of the power stroke, the tip valve closes sealing the water in the nozzle. The tip valve consists of a flat disc valve that is pivoted with respect to the nozzle opening to achieve a rapid open and close position. The pivoting of the disc is controlled by a pressure actuated hydraulic type linear actuator. The closed position of the valve is maintained by a compression spring holding the actuator's piston rearward and the open position is achieved by the flow of high pressure water to the actuator during the initial power stroke.

#### f. Firing Controls

The firing controls which are conveniently located in the rear of the water cannon consists of two control handles, safety, trigger, sight and a control lever for limiting the output of the gas generator.

##### Control Handle

The control handle is a 50 caliber machine gun type dual handle that is grasped in both hands for the manipulation and aiming of the water cannon. The safety and firing triggers are located conveniently to the handles to permit operation during two handed manipulation of the gun.

##### Safety

The safety which pivots about the top of the left handle basically controls the safety and trigger of the Ithaca shotgun receiver and has to be depressed before the water cannon firing trigger can be actuated.

##### Trigger

The trigger through a series of linkages controls the receiver actuating mechanism with respect to the firing sequence. The trigger which is located on the right hand handle is controlled by the safety which must be depressed before the trigger can be actuated.

##### Sight

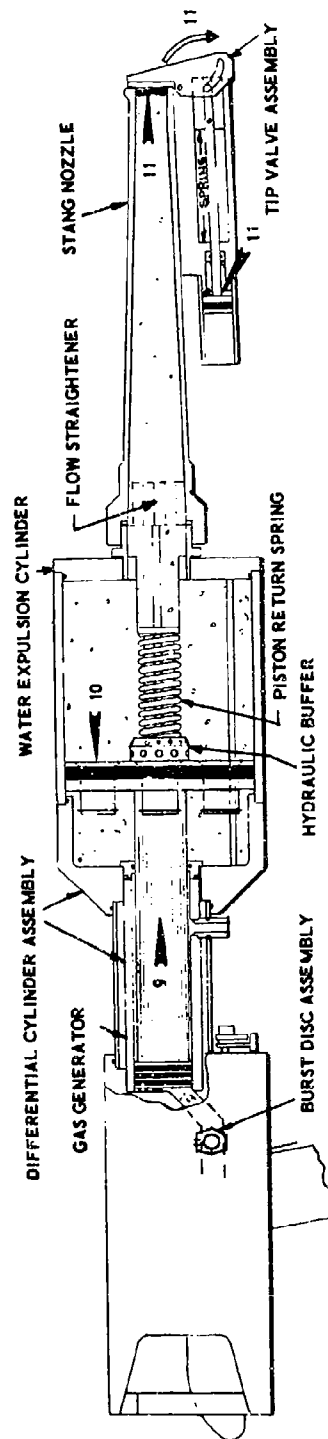
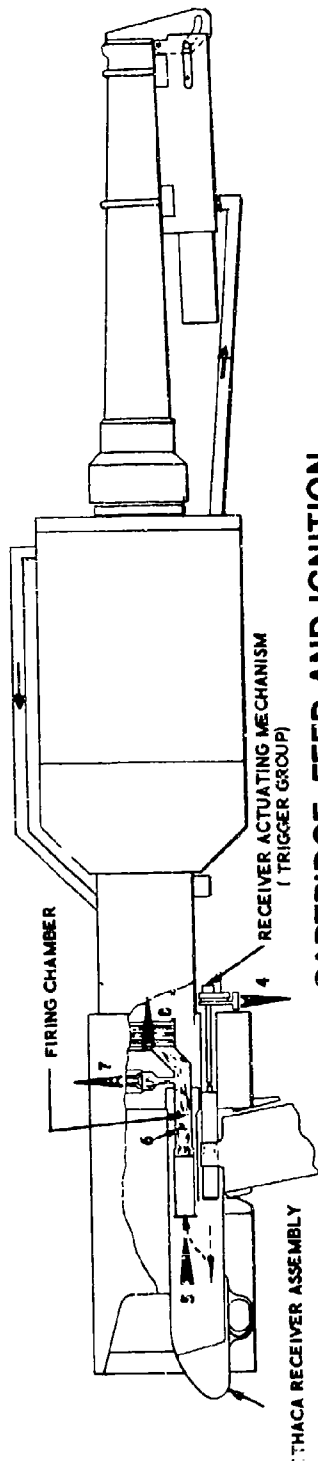
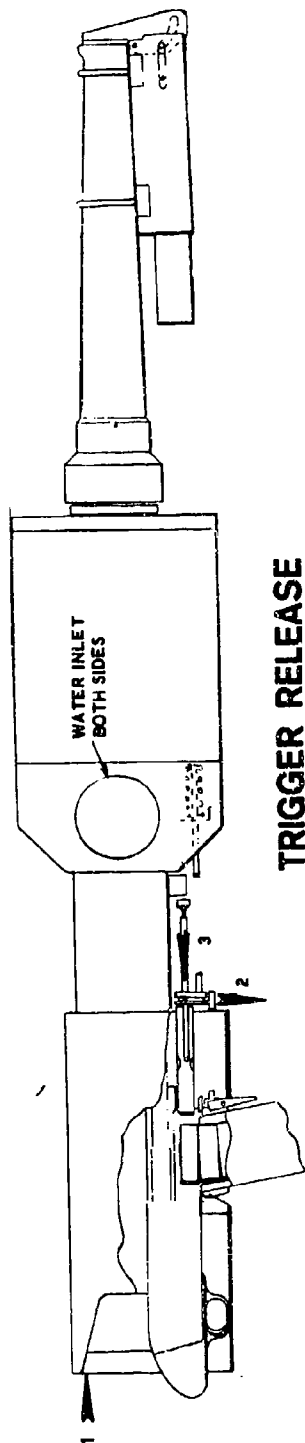
The sight utilized on the cannon is basically an iron sight which consists of a post element on the gun muzzle and a leaf element containing range graduations on the rear of the weapon.

##### Gas Pressure Control Lever

This control lever through a camming device controls the opening in the exhaust relief valve which permits hot gases to be exhausted during the power stroke and thus reduces the power in the stroke for desired low energy shots.

#### 3. Water Cannon Mount

The function of the mount is to provide the necessary structural support, the required water flow and the necessary degree of freedom



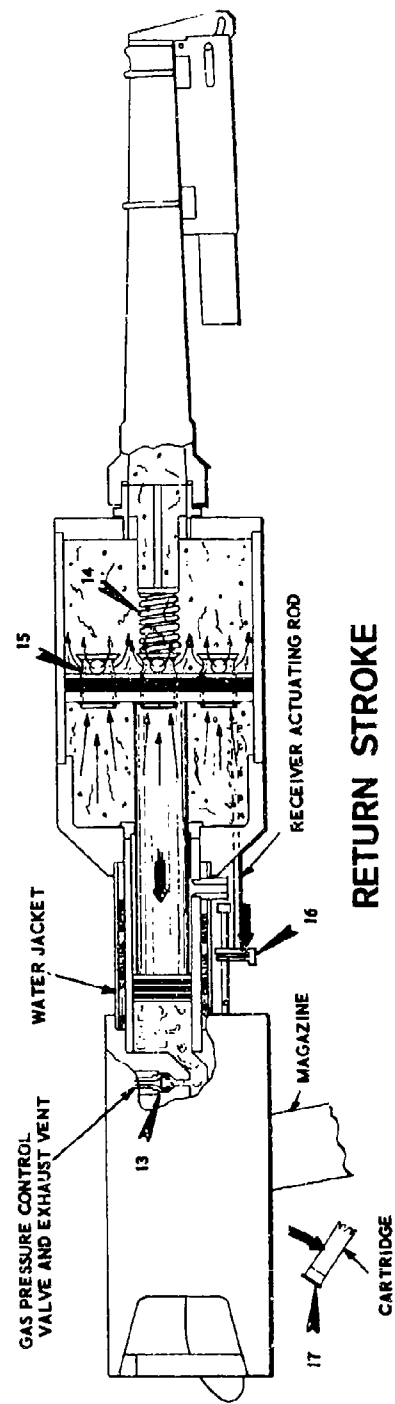
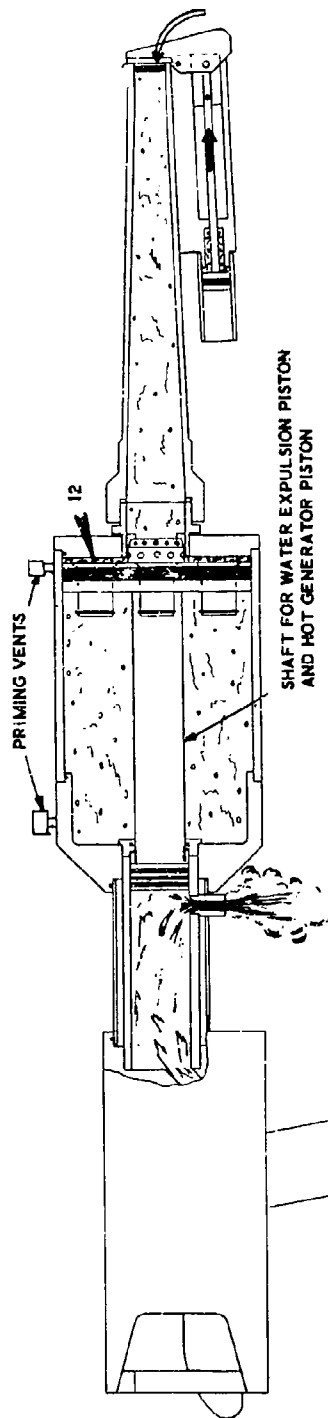
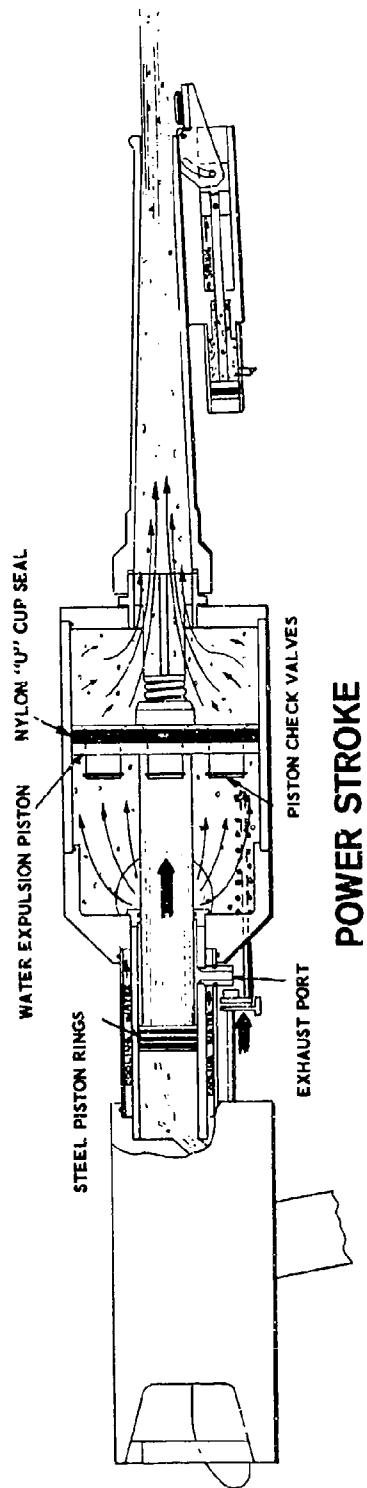


Figure 10. Sequence of Operation

of motion to permit the cannon to be readily aimed and fired in azimuth and elevation. The mount consists of a tubular tripod type structure which rigidly supports a hydraulic trunnion for mounting the cannon and associated 4 inch diameter PVC piping (water fill) that connects to the water tank. The trunnion is a Eikhart hydraulic trunnion (fire hose type) that provides freedom of motion in two phases. The trunnion comes equipped with both an azimuth and elevation lock and the joints containing the seals are ball bearing mounted to provide ease of movement. A check valve is provided in the piping to the tank to prevent loss of prime in the water cannon.

#### 4. Water Tank

The water tank is a 50 gallon drum that is interconnected to the piping of the water cannon mount and is the reservoir for providing a water supply for the cannon. Mounting internally on the side of drum is a priming pump which is used in the initial priming of the cannon.

#### B. Operation of Model

The Ballistic Actuated Water Cannon feasibility model was designed as a magazine-fed, gas cartridge-actuated device which will fire one and one-half gallons of water on each trigger pull. The rate of fire will depend upon the dexterity and skill of the operator but the unit was designed to recycle in .5 seconds. The water slug is propelled at approximately 161 ft/sec by a water pressure of 175 psi.

The sequence of operation is shown in Figure 9.

- o To initiate the firing sequence the operator must first depress the "ARM" button, 1). this simultaneously moves the safety button of the pump action to fire position and pulls the trigger of the pump action. For this particular pump action this will allow the cartridge to fire immediately after the round is charged into the chamber and the breech lock secured.
- o The operator must then depress the "FIRE" button. This motion is then transmitted by a shaft and a rotating mechanism to produce a downward force on the escapement at 2). This escapement controls the sequential release of two spring loaded shafts. The first shaft, 3), pushes the cartridge from the magazine into the receiver area while also locking out the release of the charging linkage. At the end of its stroke a groove in the shaft allow further downward motion of the escapement, 4), and the charging handle of the pump is thrust forward which lifts the round, aligns it with the chamber, inserts it, 5), in the chamber, locks it in place, and immediately releases the firing pin to initiate the primer.

- o As the gas pressure increases due to gas generation a small valve, 7), closes (vent valve for piston return) and the gas pressure on the piston face, 3), increases. When the pressure gets large enough to overcome static friction and the return spring force, the twin piston moves slightly, 9), to lock the 6 check valves, 10), by the differential pressure across the valves. The pressure then increases until the pressure on the muzzle valve face, 11), and the muzzle valve piston, 11) overcomes the spring force and allows the valve to open. This allows the dual piston to travel forward projecting the water at an average velocity of approximately 160 ft/sec. During the power stroke the partial pressure produced behind the main piston allows atmospheric pressure on the surface of the drum to force water past the check valve in the water feed line. This flow continues up the piping and through the heart shaped trunnion into both sides of the cylinder providing immediate refill water ready for the next round. The cylinder walls with the high pressure high temperature gas must be cooled to maintain the maximum rate of fire. Water is fed through tubes on both sides of the unit to the rearmost part of the water jacket. During the power stroke the differential pressure across the water piston face drives water through the tube to allow a forward flow of cooling water in the jacket. During the return stroke the flow is reversed and considerably reduced due to the small pressure differential across the piston. During this stroke the escapement has traveled forward to latch-up and secure the two spring-loaded shafts for the next cycle.
- o After the power stroke has progressed through 7.12 inches the high pressure piston face passes over, and exposes the exhaust port reducing the cylinder pressure to atmospheric pressure. The piston is still moving forward due to its own momentum and that of the trailing water. A decelerator ring on the piston face gradually closes off the orifice from which the water can escape. This gradually increases the water pressure, 12), on the piston face causing deceleration. When the piston pressure drops off, the spring in the muzzle valve forces the muzzle valve closed, trapping the water and preventing or minimizing air from getting into the piston area.
- o When the gas pressure in the small cylinder falls below 30 psi g, the small valve, 13) opens allowing the residual exhaust gasses to be forced through a side exhaust port during the piston return stroke.

- o The return stroke is accomplished by means of the large spring, 14), which forces the dual piston rearward. As soon as the pressure on the rearward side of the water piston exceeds that of the forward side, the 6 check valves open, 15), allowing the water to transfer from one side of the piston to the other which allows the dual piston to return to the reset position. During this stroke the rod, to which the escapement, 16), is attached, is forced by the dual piston to return to its most rearward position. This motion is used to force rearward the charging/ejection handle of the pump action ejecting the spent cartridge, 17). This completes the cycle.

Other features built into the system are:

- o Priming pump - this hand pump for priming could be replaced by a 12-volt low flow rate pump. It is intended to prime the cylinder when the system has lost its supply either by running out of water during operation or removal of water for storage.
- o Over pressure burst disk to protect personnel from accidental system explosion.
- o Trigger lock out when magazine is empty. The trigger cannot be depressed unless a cartridge is ready for feed.
- o Future range selection switch -

The means has been provided to selectively (4 positions) bleed off gas for low pressure short-range shots. Considerable testing will be required with several cam sizes produced to establish the usefulness of this feature and the effect that is to be provided.

### C. Evaluation of Model

#### 1. General

The test program that was used to determine the feasibility of the water cannon essentially consisted of a series of development type functional tests for establishing the subsystem functional capabilities with respect to the program objectives followed by a demonstration of the unit's overall system capability. The test program outlined below consists of both static and firing type tests utilizing the following test equipment: Pendulum (from preliminary model test), hydraulic pressure gage and high speed camera.

## Subsystem Functional Test

### Static Test

Cartridge feed, extraction and ejection

Leak test

Cycling of firing mechanism and piston assembly

### Firing Test (single and semi-automatic mode)

Initiation of cartridge

Cartridge feed, extraction and ejection

Output of water expulsion cylinder

Water fill capability

Hydraulic and gas leak integrity

Operation of tip valve

Cycling performance

Exhaust

Structural capability

## System Capability Demonstration

### Firing Test (single and semi-automatic mode)

Cycling performance

Water pulse performance (target)

## 2. Discussion of Test Results

The test program for this device commenced with the static test which initially consisted of manually actuating the receiver actuating mechanism to determine cartridge feed, extraction and ejection functional performance.

Repeated hand charging tests of the cartridge feed, extraction and ejection system and trigger group indicated that additional design changes would have to be incorporated into this area.

The modifications to the actuating mechanism were completed and functional testing of the unit was continued. Utilizing high pressure nitrogen as an energy source, the cannon was cycled for functional purposes. During this cycling of the unit excessive drag of the large piston's seal prevented the piston from returning to its original position.

To correct this condition of excessive drag the nylon seal of the water expulsion cylinder was machined to a smaller outside diameter. The reduced nylon diameter seal was reinstalled on the piston assembly and the unit functioned properly.

The cannon was then test fired 5 times utilizing cartridges. During this testing the muzzle control valve improperly functioned due to excessive leaking of a seal. This necessitated the disassembly and rework of the muzzle control valve and testing was resumed by utilizing a plug for the muzzle valve which precluded sequential firing.

Four test firings were conducted to test the functional cycling of the cannon without the muzzle valve. The cannon cycled satisfactorily and the cartridge feed, extraction and ejection were good. During these firings, trouble was experienced with water leakage when the trunnion was in the azimuth lock position. To stop the leakage required supporting the trunnion which immobilized the azimuth travel of the unit.

Five more firings were conducted intending to test target impact force. The cannon functioned and cycled satisfactorily, but water expulsion was of a low order and not at full potential, so target impact force data could not be obtained. During this test sequence, the trunnion elbows started to twist and trunnion yoke spread due to the recoil force from firing. To correct this condition, the elbows were pinned and clamped to the cannon body. The unit was then reassembled including the reworked muzzle valve and testing was resumed.

Comparisons of shots with the muzzle valve and without the muzzle valve indicated that the muzzle valve degrades the projection of the water rod. High speed photographs of the muzzle valve's actuation indicated that the valve does not open rapidly enough and consequently interferes with the water projecting from the nozzle. The nozzle valve also prevents the unit from completely cycling. With this valve installed, slight hand pressure on the firing return mechanism is required to complete the cycle.

During the single shot testing with the muzzle valve, the unit failed to refill the cylinder completely with water after a complete firing cycle. This amounted to approximately 1/2 pint and was consistent for about 10 test firings. Because of these difficulties, testing was resumed without the muzzle valve. This situation permitted only single shot operation since a plug had to be installed in the muzzle after each shot. Without the muzzle valve, the quality of the projected water rod was good and the pendulum movement was approximately 8 inches average for the shots.

During this period, it was noted that a delay of 3 to 4 seconds occurred between the time the primer was activated until the piston started to stroke. This situation was discussed with Olin who stated that they didn't experience this problem of the propellant burning slowly when they were proofing the rounds in their setup, but because of the problem they requested that AAI furnish 20 cartridges to Olin for evaluation. As

the result of this evaluation, Olin stated that the cartridges performed satisfactorily in their test device and that the burning problem was probably caused by the AAI gas generator. Investigation of the gas generator indicated that the exhaust relief valve and the excessive initial volume of the firing chamber are the probable causes for this cartridge problem. However, because of the limited budget and schedule, no effort will be made to substantiate and correct this condition.

The remaining test effort during this program was utilized in determining the cycle time, the water refill capability and the rapid fire capability of the water cannon.

During these tests, difficulty was experienced in operating the device in the semi-automatic firing mode due to cartridge hangup and the unsatisfactory performance of the receiver actuating mechanism which interrupted the firing sequence. This cartridge hangup condition during the firing sequence was caused by a metallic burr on the mouth of the firing chamber which caused the cartridge to become jammed between the bolt and the mouth of the chamber. Removal of the burr from the mouth of the chamber alleviated this condition. However, in the case of the receiver actuating mechanism, a major modification or redesign will be necessary in order to provide this mechanism with the functional capability necessary for the semi-automatic firing mode.

Due to the above difficulty, testing in the semi-automatic mode (rapid fire mode), was discontinued and a series of single shot tests were utilized to determine water refill capability. In this test, thirteen consecutive shots were fired as rapidly as possible and after the last shot only three cubic inches of additional water was required to completely refill the system.

With regard to single shot cycle time, a high speed camera was utilized which photographed the gun's action mechanism during a complete firing sequence. Two tests were conducted with the results listed in the following tabulation:

	<u>Test No. 1</u>	<u>Test No. 2</u>
Trigger Rel.	.10 sec.	.05 sec.
Total Cartridge Delay	.43	.33
Power Stroke	.124	.171
Exhaust	.479	.31
Return Stroke (Fill)	<u>.349</u>	<u>.303</u>
	1.482 sec.	1.164 sec.

From the above tabulation, it can be seen that the following functional

sequences consumed most of the total cycle time:

Cartridge Delay - The delay times noted in the above tabulation represent the time between primer initiation and useful output from the burning propellant. This excessive amount of time--which should be in the order of milliseconds-- is probably caused by excessive initial volume in the firing chamber.

Exhaust Time - This excessive time can be substantially reduced by enlarging the exhaust orifice to permit a greater flow of exhaust gases from the hot gas cylinder.

Return Stroke (Fill) - This time can also be substantially reduced by utilizing a stronger compression spring to return the differential piston assembly. However, care will have to be exercised in this area in order to prevent excessive loss in the power stroke which has to compress the spring.

The effort with regard to system demonstration was discontinued because of the functional difficulties experienced with the receiver actuating mechanism and the tip valve. The system operation of this unit which is dependent on the sequential operation of each subsystem was very sporadic with respect to cycling performance and the use of the tip valve precluded the acquisition of meaningful water pulse output data.

### 3. Feasibility Determination

#### a. General

The purpose of this program was to determine the feasibility of the cartridge-actuated unit that was developed. For this program, the basic objective was to achieve fundamental improvements in the rapid projection of 1.5 gallons of water at a pressure of 175 psi. This objective was to be achieved through the utilization of the high potential energy inherent in a cartridge propellant and the use of a standard shotgun receiver to provide the required rapid fire capability.

In the determination of system feasibility, the primary concern is to establish the performance of the subsystems that are directly identified with the major design objectives, and then to determine to what degree the subsystems meet the intent of the objectives. The remaining subsystems--which are ancillary in nature in that they do not establish the major performance features for the system--are only of secondary importance in the evaluation.

In this context, the following paragraphs identify and discuss the test performance of the various subsystems in terms of subsystem and system capability.

## b. Discussion of Functional Performance and Test Results

### Primary Subsystems

#### o Cartridge

This unit which provides all the system energy consists of a standard 12-gauge shotgun case, percussion primer, igniter and a slow burning propellant was developed and fabricated by the Olin Corporation to meet the required gaseous output prescribed by AAI. The cartridge from a fit and function standpoint performed well in the magazine and receiver; the primer functioned perfectly; and the gaseous output of the cartridge was satisfactory with respect to time, pressure and volume. The cartridge propellant burns relatively cleanly, and the unburned residue does not adversely affect the steel piston rings or the actuation of the piston.

The only problem that occurred in this area was the slow ignition of the cartridge, which, from a system standpoint, adversely affects the cycling time of the system. Discussions with, and further proof testing of cartridges by the Olin Corporation, established that the problem was not with the cartridge but in the excessive initial volume of the firing chamber. Consequently this problem can be resolved by simply reducing the initial volume to approximately 2 in<sup>3</sup>.

In general, therefore, the cartridge developed by Olin does meet the system's energy requirements, functions well with regard to initiation and ignition, and performs satisfactorily from a mechanical viewpoint in the magazine and receiver.

#### o Gas Generator

The hot gaseous output from the cartridge is utilized to stroke the piston in the water-cooled gas generator at a given rate and force level, and is the power stroke that is used for expelling the water pulse through the nozzle. This unit performed all of its functions satisfactorily except in the area of initial firing chamber volume--which has been discussed previously--and the time required for exhausting the hot gases from the cylinder.

After approximately 50 firings, the hot gases and residue had little or no corrosive effect on the steel piston rings or cylinder, and the steel piston rings still provided an effective seal. The .4 second average exhaust time is excessively high for the system cycle time, but can be readily corrected by increasing the diameter of the exhaust port. As a whole, this type of exhaust system in conjunction with the steel piston rings appears admirably suited for rapid operation.

#### o Water Expulsion Cylinder

The water expulsion cylinder--which is directly

connected in series to the gas generator--performs the functions of water fill and expulsion and supplies water to the gas generator for cooling purposes. The water expulsion worked satisfactorily and met or exceeded the Exotech Unit's output performance, but the water fill has not been completely authenticated.

The reason for this lack of authentication is that the difficulties in gun cycling and tip valve leakage prevented the firing of a long series of shots in rapid succession which would have provided the answer to the water fill question. However, in a simulated rapid fire test (manual cycling) the water volume in the cannon decreased by about only 3 in<sup>3</sup> after 10 firings.

The piston return spring is utilized to return the piston assemblies after completion of power stroke and exhaust cycle. The present spring is somewhat marginal in completing the return stroke, but this can be corrected by utilizing a spring with a higher preload.

The hydraulic buffer which is mounted on the front of the large piston is utilized to decelerate the piston assembly at the completion of the power stroke. This unit has been performing satisfactorily since no apparent damage is visible on piston or cylinder head after 50 firings.

#### o Receiver

The receiver is the standard Ithaca shotgun receiver and provides the system with a firing chamber and a cartridge feed, extraction and ejection mechanism. Throughout the testing, this unit has functioned satisfactorily and reliably in the single shot mode. During the testing, the rapid fire capability of this receiver in this application could not be proven out due to cycling difficulties caused by the receiver actuating mechanisms.

However, because of this gun's proven performance in the commercial field, and the fact that the water cannon's firing rate is well within the capabilities of the Ithaca's action, the use of this receiver should provide the water cannon with an effective and functionally sound cartridge feed, extraction and ejection mechanism.

### Secondary Subsystems

#### o Receiver Actuating Mechanism

This unit is basically the mechanized control link between the receiver and the differential cylinder assembly. It is the triggering mechanism for the system and provides the necessary mechanical forces and timing for coordinating and actuating the receiver mechanism with respect to the differential cylinder assembly.

The functional performance of this unit in conjunction

with the marginal piston return spring has been unsatisfactory and prevented system testing. Many changes and modifications have been made to the unit without really correcting the deficiencies of the unit.

The major problem in this design is in the area of the trigger mechanism. The trigger mechanism, which is a detent type of mechanism, is an integral part of the receiver actuating mechanism and travels back and forth during the stroking of the mechanism. With this arrangement, the inherent springiness of the push-pull type control rods which make up the receiver-actuating mechanism makes the detent locking of these rods critical and difficult. After a relatively few cycles, the locking surface on the hardened rod would brinell, and together with the springiness of the system, would make the trigger ineffective.

The other troublesome problem in this area had to do with the disassembly of the actuating mechanism for repair. In the configuration of the actuating mechanism, the main control rod of this assembly was in effect fastened to the inner surface of the rear expulsion cylinder head. Consequently, to remove the receiver actuating mechanism from the cannon required the complete disassembly of the spring-loaded expulsion cylinder assembly.

Essentially this mechanism will have to be redesigned and probably should provide for a trigger that is stationary and not subject to the springiness and vibrations inherent in a locking system that reciprocates. Attention should also be given in the area of disassembly and maintenance provisions.

#### o Cartridge Magazine and Cartridge Feed

Both the magazine and the feed from the magazine to the cartridge tray in the receiver worked satisfactorily. In the event that the receiver actuating mechanism is redesigned, the present cartridge feed should be incorporated into that new design.

#### o Nozzle and Flow Straightener

The presently used nozzle has been satisfactory. However, the vanes in the flow straightener have been damaged to the extent that they interfered with the flow of water through the nozzle and had to be repaired.

#### o Trunnion Assembly

The hydraulic trunnion (250 psi) is a standard mount for a fire engine. During the testing program three serious deficiencies in the trunnion occurred. The azimuth seal and bearing do not perform satisfactorily, and provide insufficient rigidity for the water cannon. The azimuth lock is unsatisfactory in that, in the locked position, it causes the azimuth seal to leak.

However, the major problem that was experienced with this trunnion was in the elevation axis. Under repeated firings, this hydraulic and structural point started to bend and permitted the points to leak badly. To rectify this situation required pinning the joints and a redesign of the area where the trunnion attaches to the cannon. This trunnion should be replaced with a better designed unit.

- o Water Cannon Mount

The water cannon mount, except for the trunnion assembly, functioned satisfactorily.

- o Tip Valve Assembly

The tip valve, which is water pressure actuated, controls the leakage of the water from the nozzle except during the power stroke. The actuation time of the valve (opening and closing) was too long, and consequently it interfered with the stream of water flowing from the nozzle. The remedy for this condition may be simply replacing the present return spring with a weaker spring to permit the valve to open faster. However, it appears more likely that the valve will have to be redesigned as a relief or check type valve that is internally mounted in the nozzle to alleviate the valve face impinging on the water stream.

- c. Summary

From a system operational standpoint, the results derived from the test program were inconclusive because of the difficulties experienced with the operation and function of certain subsystems. The difficulties with the receiver actuating mechanism precluded any real assessment of the Ithaca receiver's semiautomatic firing capability, and the performance of the tip valve negated meaningful data with respect to system performance (cycling capability accompanied by effective water pulse output).

Because of these problems, the determination of feasibility from the above standpoint would be inaccurate and fail to disclose the operational potential of the system. However, the following meaningful assessment of the system's capabilities is made by relating the individual subsystem performance to the major design features of the system.

The four subsystems included in the primary group establish the system's major design features and have, in general, performed their individual functions satisfactorily and consistently. Collectively, they have compatibly functioned together, and, with the secondary subsystems, produced a water output performance that has met the desired objectives of the program.

In regard to the rapid fire capability of the receiver, the difficulties with the receiver actuating mechanism (secondary subsystem),

which provides the mechanical forces and triggering for actuating the receiver, precluded acquiring rapid fire cycling test data. This situation does not reflect on the rapid fire capabilities of the receiver action, but points out the need for a well designed mechanical linkage and trigger group which will properly cycle the receiver. On the single-shot tests, the Ithaca receiver did perform its cartridge feed, extraction and ejection functions satisfactorily throughout the test series. With regard to cycling, the inherent rapid fire capability of this receiver is apparent in the sound design of the mechanism, and its performance and safety has been amply demonstrated in the commercial field over a long period of years.

The tip valve probably functioned satisfactorily in the area of gun cycling, but its relatively slow actuation during the power stroke did adversely affect the coherency of the projected water pulse. This unit, which is a secondary subsystem, performs a subsidiary function in that it only prevents water leakage from the nozzle, but doesn't contribute in a positive way to the water pulse's output performance. Consequently, this problem must be solved by utilizing a valve that will maintain the water in the nozzle, and then, during the power stroke, fully open without interfering with the projected stream.

The remaining subsystems, in general, performed their intended functions satisfactorily, and essentially had no adverse effects on overall performance. Various improvements will have to be made to some of the subsystems, such as the trunnion, but this is a product improvement type effort rather than one of feasibility.

In summary, it appears reasonable to assume that the water cannon developed under this contract is a feasible system, and could, with modifications, perform its intended use. The water pulse output met all expectations, and both the water and cartridge feed systems appear to function well on a subsystem basis. The receiver actuating mechanism, however, which is the heart of the cycling problem, will have to be subjected to major modification or redesigned.

## V. CONCLUSIONS AND RECOMMENDATIONS

The Cartridge Actuated Water Cannon that was developed under this program represents a new type water pump system in the field of civil disturbance control. While the results of the test on this device were inconclusive from an operational point of view, the testing did demonstrate that the basic subsystems of the concept that were identified with the system's performance features, did perform to the degree necessary to establish the feasibility of the cartridge actuated pump concept.

The utilization of this innovative pumping method provides this system with a high growth potential, and a unique effective operation capability in that it offers a simpler and more reliable method for pumping water pulses than any of the present systems. Because of its simplicity of operation, lightweight, compact size and firing readiness capability, this system is especially adaptable to small truck installation, and offers the following operational advantages over the current pumping systems.

- o A lightweight system which does not require permanent-type mounting/stowage or precise alignment of components.
- o Modular construction which results in minimum size for equipment and permits maximum flexibility for vehicular installation.
- o Minimum use of auxiliary services.
- o Greater operational reliability and minimum preventative maintenance.
- o Manipulation of cannon for azimuth and elevation sighting and travel is readily performed because trunnion is not pressurized.
- o Operating controls are few and simple to actuate.
- o System is easy to maintain in "ready-to-fire" condition.

In summing up the results of this program, it becomes apparent that this model has unquestionably achieved a fundamental improvement in the area of water pulse projection. Also, what is not quite so obvious, is that it basically has the inherent capability of performing this projection rapidly and reliably.

The problems that the present model experienced in the rapid fire mode appear to be subject to rather straightforward design solutions.

The solutions to these problems, together with the inherent capabilities that have been exhibited by the various elements of the system, should then provide a pumping unit that is effective, operationally sound and able to realize the advantages that are inherent to this design. The following recommendations are basically the functional design areas in which improvements will have to be made in order for this model to effectively function as a system:

- a. Redesign receiver actuating mechanism with special emphasis on gun charging and improved trigger actuation.
- b. Replace tip valve with a pressure actuated valve or check valve mounted internally in rear of nozzle.
- c. Correct excessive cartridge initiation time by reducing initial volume of firing chamber and reduce expulsion of exhaust gases by enlarging diameter of exhaust gas port to achieve the desired firing rate of .5 second per shot.
- d. Replace trunnion with unit containing improved elevation and azimuth travel and of lighter weight.
- e. In the redesign of actuating mechanism, provide provisions with respect to expulsion cylinder disassembly for the units to be readily disassembled.